# SCHOOL NETWORK PLANNING IN CAPE VERT: MAXIMIZING ACCESSIBILITY VS MINIMIZING INVESTMENT

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## ABSTRACT

Despite the efforts recently made in Cape Vert to improve the school networks of its municipalities, many problems still persist and need to be tackled in the near future. In this article, we present a study made for the municipality of Santa Cruz (approximately 35,000 inhabitants), to help identify the best evolution of the municipality's elementary school network for the planning horizon of 2015. The study was conducted considering the following main objectives: the network should satisfy the elementary education demand in 2015; the accessibility of students to schools should be as large as possible; and the investment in the expansion of the network should be as small as possible. The planning problems involved in the study were represented with discrete location-allocation models. In spite of the relatively large size of the models, they were comfortably solved with XPRESS-MP, one of the most powerful integer optimization programs currently available on the market.

## KEY WORDS

School network, public facilities, location-allocation model, integer optimization, Cape Vert.

## INTRODUCTION

Cape Vert is an African country composed of ten islands located in the Atlantic Ocean next to Senegal. Because of the fast socio-economic evolution of the country in the last decades, its classification according to the Human Development Index of the United Nations recently changed from "Low" to "Medium". In spite of this, many socio-economic problems persist, and need to be tackled in the near future. Among them, those related to education are certainly among the most relevant.

After the independence in 1975, the government of Cape Vert defined education to be one of the strategic sectors for the development of the country. As a consequence, the sector went through important transformations since then, and particularly since 1994, within the context of a major reform of the educational system. For the implementation of this reform,

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important planning efforts were made, which led to the approval of an educational charter for the country and school construction programs for all municipalities. Despite this effort, it is recognized today that the solutions adopted in the educational charter were not the best possible ones, and need to be improved.

In this article, we present a study made for one of the municipalities of Cape Vert – the municipality of Santa Cruz – to help identify the best evolution of the municipality's elementary school network for the planning horizon of 2015. One of the reasons why the network needs to change is because the occupation rate of several schools is either excessively high or excessively low. Another reason is the increase in the duration of elementary education from six to eight (or nine) years that is planned to occur in the near future. The study was conducted considering the following main objectives: the network should satisfy the elementary education demand in 2015; the accessibility of students to schools should be as large as possible; and the investment in the expansion of the network should be as small as possible.

## PLANNING PROBLEMS

In this section, we present the problems dealt with in the study reported in this article. First, we provide geographic information about the municipality of Santa Cruz. Then, we characterize the educational demand from the various zones of the municipality. Next, we describe the existing school network. And, finally, we state the planning objectives to be fulfilled by the network in 2015.

### MUNICIPALITY OF SANTA CRUZ

The municipality of Santa Cruz is located in the Eastern part of the Santiago Island (Figure 1). The distance between its main town, Pedra Badejo, and the city of Praia, the capital of Cape Vert, is about 30 km. The municipality occupies an area of 149 km$^2$ (i. e., 15% of the island's total area), distributed across 39 zones. In 2000, date of the latest census, the total population of the municipality was 32,965 (INECV, 2000). Approximately 1/2 of this population had less than 15 years of age, and 2/3 had less than 25. The most populous zone, Pedra Badejo, had a population of 8,517. The other zones with population above 1,500 were Cancelo (2,037), Santa Cruz (1,933), Achada Fazenda (2,370). All these zones are located close to Pedra Badejo, on the Atlantic coast.

In the last five decades, the population of the municipality increased steadily from 9,568 to 32,965, at an average annual growth rate of 2.5% (Figure 2). During the last ten years, the growth rate was 2.4%. According to a forecast made by the Cape Vert Bureau of Statistics, in 2015 the population of the municipality will be 43,795, which means a growth rate of 1,9%.

### EDUCATIONAL DEMAND

In the 2003-04 school year, a total of 11,460 students attended elementary and secondary education in the municipality of Santa Cruz (GEP/MEVRH, 2004). In Cape Vert, school education is organized in three main levels: elementary, with six years (three phases of two years each); secondary, also with six years; and higher education. Higher education is not offered in the municipality.

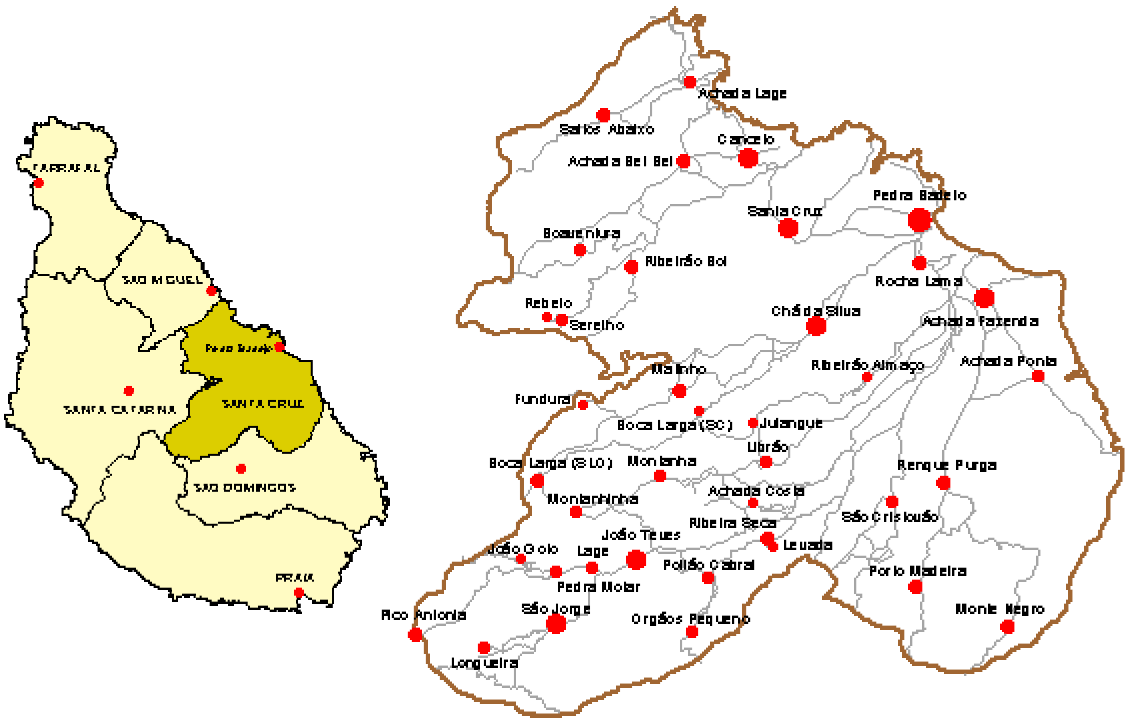


Figure 1: Island of Santiago and Municipality of Santa Cruz

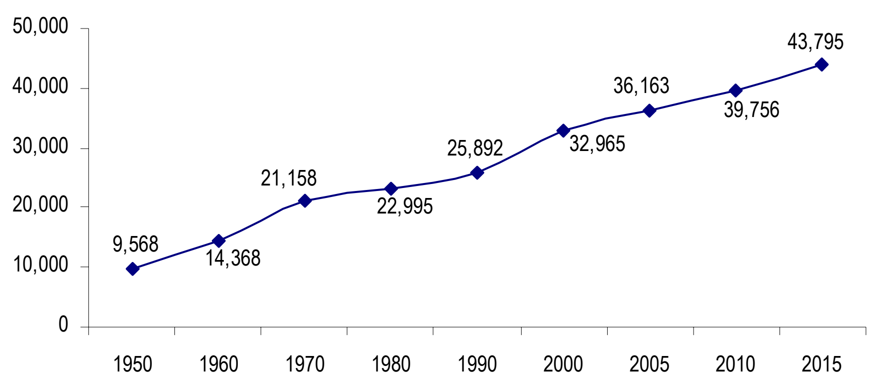


Figure 2: Demographic Growth of the Municipality of Santa Cruz

The number of elementary education students in the municipality was 7,976 (that is, 69.6% of the total number of students). The gross enrollment rate for this level of education, obtained by dividing the number of students with the 6-11 year old population, was approximately 110%. It is larger than 100% because some students are older than 11 (either because of failed progression or because of late entrance).

For the year 2015, the number of elementary education students was forecast on the basis of the following assumptions: (1) the distribution of population across age groups will be the same as in 2000; (2) the distribution of population across zones will be the same as in 2000; (3) the gross enrollment rate for the 6-11 year old population will decrease to 105%; (4) the students will be evenly distributed across the three phases of elementary education. The forecast is shown in Table 1.

Table 1: Forecast of Elementary Education Students for the Municipality of Santa Cruz

| Zone | Elementary Education Students per Phase (2015) | Zone | Elementary Education Students per Phase (2015) |
|---|---|---|---|
| Achada Lage | 51 | Monte Negro | 60 |
| Saltos Abaixo | 78 | Levada | 21 |
| Achada Bel Bel | 74 | Poilao Cabral | 35 |
| Cancelo | 206 | Orgaos Pequeno | 50 |
| Boaventura | 45 | Joao Teves | 144 |
| Ribeirao Boi | 54 | Lage | 45 |
| Serelho | 33 | Pedra Molar | 45 |
| Rebelo | 27 | Joao Goto | 20 |
| Pedra Badejo | 859 | Montanhinha | 35 |
| Rocha Lama | 64 | Boca Larga | 62 |
| Santa Cruz | 195 | Longueira | 42 |
| Achada Fazenda | 239 | Pico Antonia | 71 |
| Achada Ponta | 41 | Montanha | 43 |
| Cha da Silva | 124 | Achada Costa | 24 |
| Matinho | 67 | Ribeira Seca | 62 |
| Julangue | 2 | Sao Cristovao | 37 |
| Librao | 43 | Fundura | 17 |
| Ribeirao Almado | 15 | Boca Larga | 14 |
| Renque Purga | 86 | Sao Jorge | 130 |
| Porto Madeira | 64 | Total | 3324 |

## SCHOOL NETWORK

In the 2003-2004 school year, the elementary school network of the municipality of Santa Cruz was composed of 35 schools with 161 classrooms (Figure 3). Of the 35 schools, 19 were designated as central schools and the remaining 16 as satellite schools. The satellite schools are administered by central schools. Approximately 1/3 of the schools was classified by the Ministry of Education as being in good condition (the others were classified as being in reasonable or bad condition). The schools operate on a double-shift schedule, that is, there are two classes per classroom (morning and afternoon). The average number of students per classroom was 49.5. In several coastal zones, e. g., Chã da Silva (67.8), Cancelo (66.5), Achada Fátima (64.1), and Pedra Badejo (62.9), the average was largely exceeded. Instead, in off-coast zones, e. g., São Jorge (25.3), Fundura (28.3), Monte Negro (30.0), and Ribeira Seca (31.0), the average was far from being attained (GEP/MEVRH, 2004).

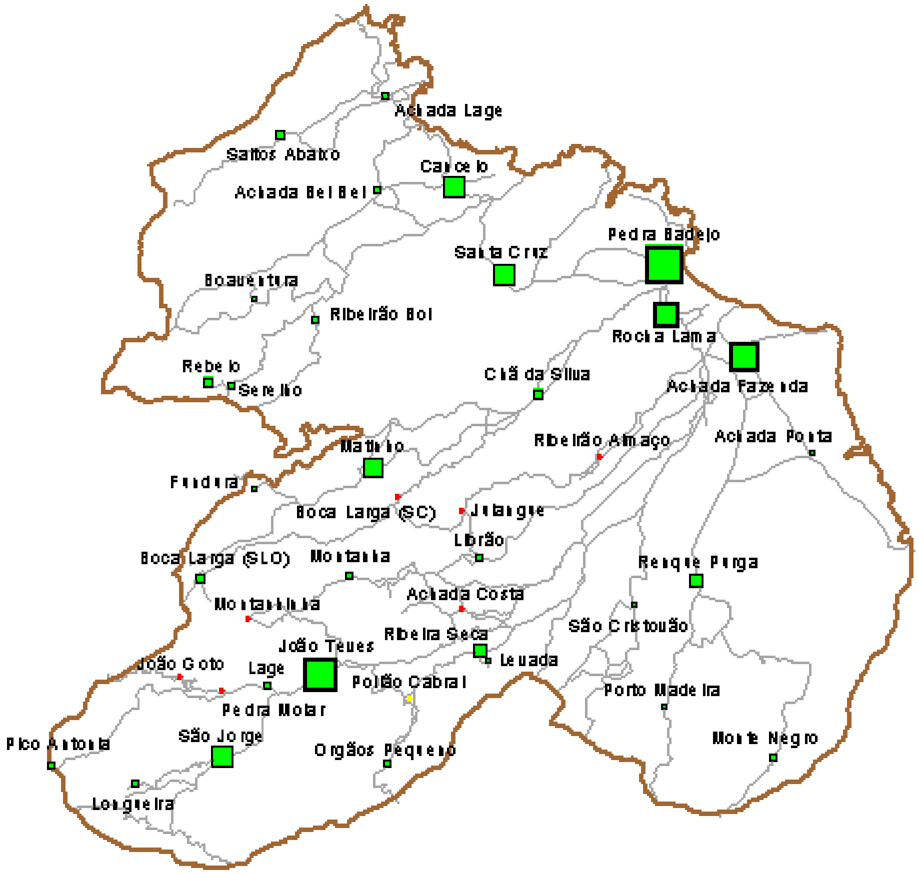


Figure 3: School Network of the Municipality of Santa Cruz

## PLANNING OBJECTIVES

The general objective of the study reported in this article was to define a school network capable of satisfying, in 2015, the elementary education demand coming from the 39 zones of the municipality. The school network should be designed to meet two strategic objectives: (1) maximize the accessibility of students to schools; and (2) minimize the investment on the expansion of the network. In addition, it should verify five operational objectives: (1) students should be allocated to schools located within 6 km of the zone where they live; (2) students from the same zone should be allocated to the same school or to schools located in the same zone (as shown in Teixeira and Antunes, 2005, this rule leads to solutions that are easier to interpret and to explain, being therefore easier to accept by the public); (3) for pedagogic reasons, the number of students per classroom should not exceed 50 (that is, 25 students per classroom in a double-shift school); (4) for similar reasons, all schools should offer all three phases of elementary education, which means that they should be composed of modules of three classrooms, one for each phase; (5) for economic reasons, the rate of occupation of each school should be, at least, 70%.

## OPTIMIZATION MODELS

The number of possible solutions to the planning problems described in the previous section is extremely large. Therefore, the problems can only be dealt with efficiently with recourse to optimization modeling. The models applicable to public facility planning problems are known as location-allocation models. These models are classified as continuous or discrete, depending on whether the facilities can be located anywhere on the plain or in some points of the plain, specified in advance. In practical applications, one normally resorts to discrete location-allocation models. There is a vast body of literature addressing these models. For a textbook presentation of the subject, the reader is referred to Daskin (1995). A recent survey on the subject is available in Current et *al*. (2002). Many studies on school network planning used discrete location-allocation models, including, among many others, O'Brien (1969), Pizzolato and Silva (1997), Antunes and Peeters (2000), and Teixeira et *al*. (2005).

The model used in the study reported in this article for the accessibility-maximization objective was as follow:

$$Min\, D = \sum_{j \in J} \sum_{k \in K} d_{jk}\, u_j\, x_{jk} \tag{1}$$

subject to

$$\sum_{k \in K} x_{jk} = 1, \forall j \in J \tag{2}$$

$$x_{jk} \le r_{jk}\, y_k, \forall j \in J, k \in K \tag{3}$$

$$\sum_{J \in J} u_j\, x_{jk} \le a\, s_k y_k + a\, z_k, \forall k \in K \tag{4}$$

$$\sum_{J \in J} u_j\, x_{jk} \ge c\, a\, s_k y_k + c\, a\, z_k, \forall k \in K \tag{5}$$

$$y_k \le s_k + z_k, \forall k \in K \tag{6}$$

$$\sum_{\substack{k' \in K \\ d_{jk'} \le d_{jk}}} x_{jk'} \ge y_k,\ \forall j \in J, k \in K \tag{7}$$

$$x_{jk} \text{ binary}, y_k \text{ binary}, z_k \text{ integer}, \forall j \in J, k \in K$$

where D: aggregate travel distance (or time, or cost); $d_{jk}$: distance between center $j$ and site $k$; $u_j$: number of students of center $j$; $x_{jk}$: proportion of students of center $j$ allocated to a school in site $k$; $r_{jk} = 1$ if $d_{jk} \le d_{\max}$, $r_{jk} = 0$ otherwise; $d_{\max}$: maximum distance between a center and a school; $y_k = 1$ if a school is (or remains) installed at site $k$, $y_k = 0$ otherwise; $a$: maximum number of students per classroom; $s_k$: capacity currently installed at site $k$; $z_k$: capacity expansion at site $k$; $c$: minimum occupation rate for a school.

This integer optimization model applies to a set a centers and a set of sites, connected through a transportation network. The centers represent the zones where students live (in 2015). The sites represent the zones where schools are or can be located (which may coincide or not with centers). The decision variables of the model represent the location of schools ($y_k$), the expansion of schools ($z_k$), and the allocation of students to schools ($x_{jk}$). The objective-function (1) represents the minimization of the aggregate distance (or time, or cost) students need to travel between the center where they live to the school they are allocated to. Constraints (2) ensure that all students will be allocated to a school. Constraints (3) guarantee that students will be allocated to sites where schools are installed, and that these schools will be within a given maximum distance (6 km) of the centers where they live. Constraints (4) ensure that the capacity of schools will be large enough to accommodate the students allocated to them. This capacity is obtained by adding the existing capacity to possible new capacity. Constraints (5) ensure that all schools will verify a given minimum occupation rate (70%). Constraints (6) guarantee that there will be no schools in sites where no capacity is installed. Constraints (7) guarantee that students will be allocated to the closest school.

With regard to the investment-minimization objective, the model was the same except for the objective-function, which was changed to

$$Min\ Z = \sum_{k \in K} z_k \tag{8}$$

Objective-function (8) represents the total expansion of the school network, which was taken as a good indicator of the investment expenses needed to improve the network.

It is worth noting that, unlike the accessibility-maximization model, the investment-minimization model may have a large number of global optimum. To break ties, after determining an optimum to the model, $Z^*$, it is convenient to solve the accessibility-maximization model again adding the constraint.

$$\sum_{k \in K} z_k = Z^* \tag{9}$$

## MODEL RESULTS

In this section, we present the results obtained through the application of the optimization models, considering, first, the accessibility-maximization objective and, second, the investment-minimization objective. The models were solved with XPRESS-MP (Dash Optimization, 2002), one of the most powerful optimization programs currently available on the market. In spite of the relatively large size of the models, they were always solved within less than 30 seconds.

### ACCESSIBILITY MAXIMIZATION

The solution obtained for the accessibility-maximization problem with a minimum occupation rate of 70% is depicted in Figure 4. It involves the construction of schools in 3 new zones (in Montanhinha, Pedra Molar and Poilão Cabral), the closure of schools in 9, and the expansion of schools in 12 zones. The aggregate distance for this solution is 1,000 km. The total number of new modules (of 3 classrooms) to install is 33. Ten of these modules are to be located in the zone of Pedra Badejo, where an additional new school should in principle be built. If this solution is implemented, there will be schools in 25 of the 39 zones of the municipality.

We performed a sensitivity analysis of this solution by varying the minimum occupation rate to 60% and 80% (Table 2). In the first case, the aggregate distance would decrease to 494 km (-49.4%). This would occur because, being less exigent in respect to the occupation rate, schools would be closed in only 6 instead of 9 zones, thus avoiding the students living there of traveling to a school located in another zone. The total number of new modules to install would be 31, instead of 33. In the second case, the aggregate distance would increase to 2898.6 km (+189.9%), schools would be closed in 15 zones, and the number of modules to install would increase to 37.

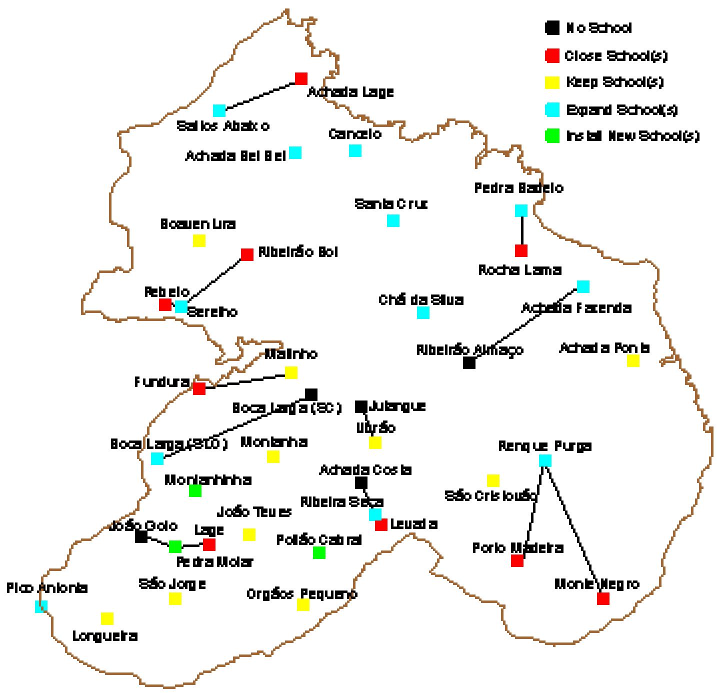


Figure 4: Accessibility-Maximization Solution for the School Network of the Municipality of Santa Cruz

Table 2: Sensitivity Analysis of the Accessibility-Maximization Solution for the School Network of the Municipality of Santa Cruz

| Minimum Occupation Rate | Aggregate Distance (km) | Number of Zones | | | | Number of Modules | | |
|---|---|---|---|---|---|---|---|---|
| | | Where New Schools are Built | Where Schools are Expanded | Where Schools are Closed | With Schools | New | Closed | Total |
| 60% | 494 | 3 | 14 | 6 | 28 | 31 | 8 | 79 |
| 70% | 1000 | 3 | 12 | 9 | 25 | 33 | 11 | 78 |
| 80% | 2898.6 | 5 | 8 | 15 | 21 | 37 | 20 | 73 |

## INVESTMENT MINIMIZATION

The solution obtained for the investment-minimization problem with a minimum occupation rate of 70% is depicted in Figure 5. It involves the construction of schools in 2 new zones ((in Montanhinha and Poilão Cabral), the closure of schools in 8, and the expansion of schools in 13 zones. The number of new modules to install, which is taken as a proxy for investment, is 30 (instead of 33 for the accessibility-maximization problem). The aggregate distance for this solution is 1,379.6 km (+38.0%). It is worth noting that the reduction in the number of modules is accomplished through changes in only two small parts of the network: the closure of the school of Chã da Silva instead of the school of Rocha lama, near Pedra Badejo; the expansion of the school of Lage instead of the opening of a new school in Pedra Molar.

As for the accessibility-maximization problem, we performed a sensitivity analysis of the solution (Table 3). The results are qualitatively similar to the ones described earlier. In particular, it is worth noting that the total number of modules is the same for each minimum occupation rate, and that the number of zones with school will also be the same, except for the minimum occupation rate of 80%, where it will be 19 (instead of 21).

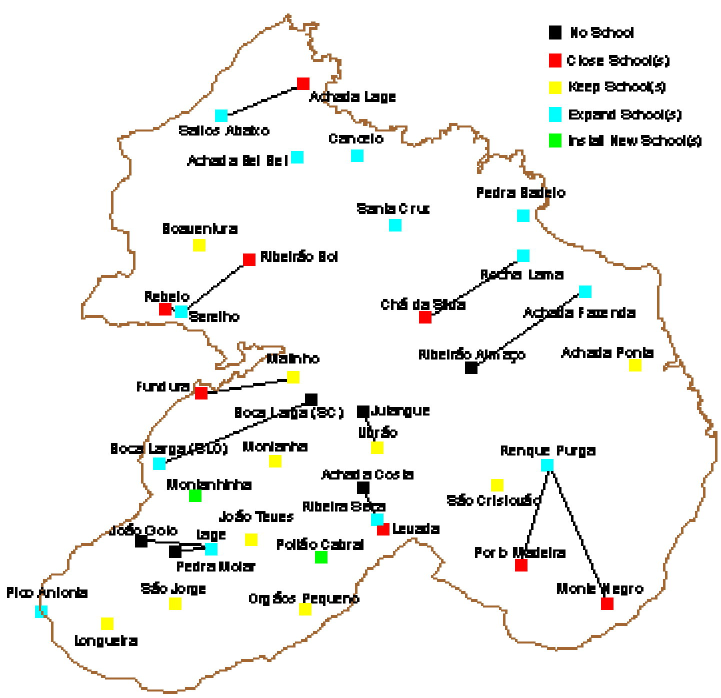


Figure 5: Investment-Minimization Solution for the School Network of the Municipality of Santa Cruz

Table 3: Sensitivity Analysis of the Investment-Minimization Solution for the School Network of the Municipality of Santa Cruz

| Minimum Occupation Rate | Aggregate Distance (km) | Number of Zones | | | | Number of Modules | | |
|---|---|---|---|---|---|---|---|---|
| | | Where New Schools are Built | Where Schools are Expanded | Where Schools are Closed | With Schools | New | Closed | Total |
| 60% | 857.6 | 3 | 14 | 6 | 28 | 29 | 6 | 79 |
| 70% | 1379.6 | 2 | 13 | 8 | 25 | 30 | 8 | 78 |
| 80% | 3371.4 | 3 | 9 | 15 | 19 | 34 | 17 | 73 |

## CONCLUSION

In this article, we presented a study made to help identify the best evolution of the elementary school network of the municipality of Santa Cruz for the planning horizon of 2015. The planning problems involved in the study were represented with discrete location-allocation models considering two objectives: the maximization of the accessibility of students to schools and the minimization of the investment in the expansion of the network. It was verified that the solutions for the two objectives were very similar. Therefore, on the basis of these solutions, the task of policy-makers in the decision process regarding the evolution of the network, would be greatly simplified.

## ACKNOWLEDGMENTS

The first authors thankfully acknowledge support received from Fundação para a Ciência e a Tecnologia through grant SFRH/BD/15347/2005.

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